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THE EFFECT OF AIR-PASSAGE LENGTH ON THE OPTIMUM FIN SPACING FOR MAXIMUM COOLING

By Maurice J. Brevoort
Langley Memorial Aeronautical Laboratory

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SUMMARY

The effect on cooling of baffle length with optimum cylinder finning is discussed. Results from tests of several streamlined cylinders are given. It is shown that by employing several baffles the cooling can be increased several times.

INTRODUCTION

The problem of cooling a finned engine cylinder may be reduced to a determination of the cylinder shape, the fin depth, the fin spacing, the fin thickness, and the baffle arrangement that will dissipate the most heat from the cylinder for a given available pressure drop Δp. A study of the available Δp has been made (reference 1) and the effect of the various elements of the baffle has been studied (reference 2). The effects of fin spacing and fin thickness have been given for one baffle length (reference 3), and the effect of fin width has been reported (reference 4). There remain, then, three unexplored possibilities for the improvement of cylinder cooling: (1) the shape of the cylinder, (2) the length of the baffle, and (3) the lowering of the heat transfer from the hot gases inside the cylinder to the cylinder wall by suitable changes in the cylinder design. The first two possibilities will be considered in this note.

POWER TO COOL

The power dissipated in cooling a cylinder is $Q\Delta p$, where Q is the volume of air passing through the fins per unit time, and Δp is the pressure drop across the cylinder-baffle arrangement. This power, with well-designed cylinder finning and baffling, amounts to the order of 1 percent of the horsepower of the engine. This power for cooling obviously does not include the power consumed in overcoming the profile drag of the cowled engine, which power must be considered when any comparison of various types of engine is made. The power that an engine develops is often limited by the cooling provided. When such a condition exists, the power required for cooling is of very small consideration. Since this power is relatively small in any case where good cylinder and baffle design is used, the solution of the cooling problem involves the use of more power for cooling. The real cooling power is the product of the volume of air passing between the fins and the actual pressure drop of the air passing between the fins. The work reported in reference 2 was concerned with making this power as large as possible with a given over-all drop in pressure across the cylinder-baffle arrangement by variations in the baffle arrangement.

Deeper fins and correctly designed baffles are two obvious constructive means of improving the cooling. Both methods are limited. Fin depth is limited by the inefficiency of the fin tip for deep fins. The effectiveness of baffles is limited by the available Δp and by entrance and exit losses that cannot be totally eliminated.

EFFECT OF BAFFLE LENGTH

The mechanism of cooling the finned air-cooled engine cylinder is essentially the same as that of the tubular radiator. The fins, baffle, and cylinder wall form air passages that perform the same function as the tubes in the radiator. The length of the baffle in the direction of the air flow determines the effective length of the tube.

When fluid flows through a tube immersed in a fluid, so that heat is either added to or extracted from the fluid moving through the tube, certain relations among the variables are known to exist. Glauert (reference 5) gives the equation for pressure drop as a function of distance, velocity, tube diameter, and viscosity. McAdams (reference 6) gives the heat-transfer coefficient as a function of specific heat, viscosity, tube diameter, velocity, and fluid conductivity. It is further known that the temperature of the fluid flowing through the tube approaches logarithmically the temperature of the tube wall. These three relations may be employed to eliminate the velocity and show the heat dissipated as a function of the pressure drop, the difference between inlet fluid temperature and tube-wall temperature, the tube length and diameter, and the various physical constants of the fluid. The foregoing relations for pressure drop and heat transfer are given in references 5 and 6 for both laminar and turbulent flow.

The effect of diameter and length can be illustrated by plotting (fig. 1) the relation for heat dissipated for the condition of turbulent flow. The abscissa is tube length, and the ordinate is heat dissipated (H) per unit frontal area (A). All three curves are for a constant pressure drop and for a constant temperature difference between inlet-air temperature and average water temperature for the radiator.

For each tube diameter there is a certain length at which the maximum amount of heat is dissipated, and the values of these maxima are very nearly the same and occur at approximately the same value of diameter-length ratio. Thus the same amount of heat can be dissipated from a short radiator having small-diameter tubes as from a very long radiator having large-diameter tubes. The curves presented in figure 1 should not be confused with similar curves for constant mass flow. In figure 1 the mass flow becomes less as the length increases, owing to the condition of constant pressure drop.

A similar set of curves can be prepared for finned cylinders by using fin spacing with optimum fin thickness and fin depth in place of the tube diameter, and baffle length in the direction of air flow in place of the tube length. These curves will show that for a particular fin spacing there will be an optimum air-passage length and vice versa. If practical difficulties are ignored, it follows that, by the use of several short baffles with optimum finning, each having the original pressure drop, the heat dissipated can be increased several times. In other words, the power to cool can be increased sveral times.

Figure 2(a) shows a baffle much like the one used in reference 3. This baffle covers half of the cylinder and, according to figure 1, a relatively wide fin spacing must be used. Throughout the discussion of the various arrangements shown in figure 2, exact multiples of lengths, fin spacings, and cooling will be used simply for illustration. Consider figure 2(b) where the baffle covers one-fourth of the cylinder. Here, since the air-passage length is only one-half as great, the fins will be twice as close together. The result is twice as much cooling surface and twice as much cooling for the cylinder as a whole.

Figure 2(c) shows a baffle that has an air-passage length only about one-sixth as long as that shown in figure 2(a). The fins would have one-sixth the spacing and six times the cooling area in unit length of baffle. The result is six times the cooling in unit length. This arrangement may be a practical means of cooling a region needing extra cooling. The main point to be gained from figure 2 is that great improvement in cooling can be realized on a particular part of the cylinder by employing a short baffle with close fin spacing.

COOLING MEASUREMENTS

In the region at the rear of both the barrel and the head of an engine cylinder, the heat transfer is very low. Heat-transfer coefficients for this region, based upon the fin and the wall temperatures, have a small value, and even that is largely fictitious. More probably the heat is conducted through the walls and fins toward the front of the cylinder to give an apparent heat transfer at the rear.

The study reported in reference 2 indicates that, even with the best baffle arrangement, there is a large mixing loss at the baffle exit. Any means of decreasing the mixing loss and increasing the cooling surface would materially improve the cooling at the rear of the cylinder. Several arrangements, three of which are shown in figure 3, were tested in the manner described in reference 2. The same heat input, pressure drop, fin spacing, and fin thickness were used. The thermocouples were sunk into the metal of the streamlined cylinders (fig. 3) so that the temperatures were measured on all cylinders at identical positions with respect to the axis of the cylinder.

The temperature distribution is shown (fig. 4) for the three arrangements of figure 3, the result for the circular cylinder being included for comparison. The baffle arrangement is shown in figure 5. Arrangement 3(a) had more than 50 percent extra fin area in the rear of the cylinder and a slightly higher air velocity between the fins than the circular cylinder. It would be expected that metal (brass) would offer little resistance to the heat flow compared with the boundary layer and that a large gain in cooling in the rear of the cylinder would be realized.

One advantage of the circular cylinder is not entirely obvious. The curvature of the air passages tends to induce the flow to follow the shortest path, thus bringing the flow in contact with the cylinder wall and fin base as indicated in figure 5. This fact explains the surprisingly good cooling realized for the circular cylinder as compared with the streamlined cylinders, especially 3(a). Cylinder 3(c), as pointed out subsequently, can, by minor changes, undoubtedly be made equal or superior to 3(a).

It can be seen from figure 4 that the cooling at the rear of the cylinder can be improved about 20 percent and the cooling over the baffled part of the cylinder about 10 percent by suitable streamlining. Although arrangement 3(c) did not cool so well as 3(a), it is probable that, either by changing the baffle as shown in figure 2(c) or by using longer fins that extend down the exit duct, equally good cooling could have been obtained.

It was convenient to make these tests on a model of the cylinder barrel, but the head offers the best place for application. At present the head is streamlined to some extent. Further streamlining and more effective use of head baffles must ultimately be employed.

APPLICATIONS TO DESIGN

The results shown in figure 4, together with the explanation of the cooling in the circular cylinder by use of flow lines, may be utilized to examine the performance of the short baffle. The short baffle is shown applied to the circular cylinder (fig. 6(a)). The flow lines are included to show the tendency of the flow to follow the shortest path or the path of least resistance. A short baffle thus tends in some measure to defeat its own purpose by inducing most of the flow by the fin tips. Such flow requires power but does not contribute to cooling. This figure also illustrates the need for closely fitting baffles so that the flow will be forced to take place between the fins instead of following the path of less resistance formed between the baffle and the fin tips.

Figure 6(b) shows the short baffle applied to the head. The fins are usually comparatively deep on the head and therefore the tendency to use only the fin tip is exaggerated. It is seen also that the flow tends to miss the rear of the cylinder almost entirely. Figure 6(c) shows a head baffle designed to overcome both of these objections. The baffle is close to the fin tips and extends behind the cylinder in such a way as to induce the flow to go to the base of the fin to seek the shortest path. Some such means as this must be employed to develop the cooling for which deep narrow head fins are designed.

From the discussion of baffle length, fin dimensions, and flow through curved air passages, it is obvious that maximum cooling is the result of the proper choice of <u>all</u> the variables of cylinder baffling and finning.

The foregoing discussion applies only to the baffled part of the cylinder. It has been shown (reference 1) that the front of the cylinder is cooled by large-scale turbulence, but this means of cooling is not at present subject to control. It is reasonable to expect that, as engine power is increased, a point will be reached at which the cooling due to turbulence will no longer be sufficient. It has generally been expected that blower cooling would be resorted to when the available pressure drop and frontal cooling become insufficient due to increased engine power.

Now, in the present discussion, a much simpler and less expensive method is proposed; namely, increasing the number of baffles to cool any part of the cylinder that shows insufficient cooling.

CONCLUSIONS

Consideration of fundamental knowledge, in part confirmed by the experimental evidence in this report, indicates that optimum fin spacing depends on the baffle length and the ratio of baffle length to fin spacing is approximately constant. With the proper choice of fin variables, as much heat can be dissipated from a short passage as from a long passage for a given pressure drop. Heat transfer can be improved by constructing the baffle so that the air flow is uniform throughout the fin space. The tests indicate that some improvement of cooling may be achieved by streamlining the cylinder and thus increasing the mass flow of air for a given pressure drop.

Further work in this field should be directed toward a more accurate and extensive knowledge of the detailed mechanism of the air cooling process on finned cylinders. With such knowledge as a basis, the problem of determining the optimum cooling arrangement of practical air-cooled cylinders, utilizing all the factors within the designer's control, can be subjected to rational investigation.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 17, 1937.

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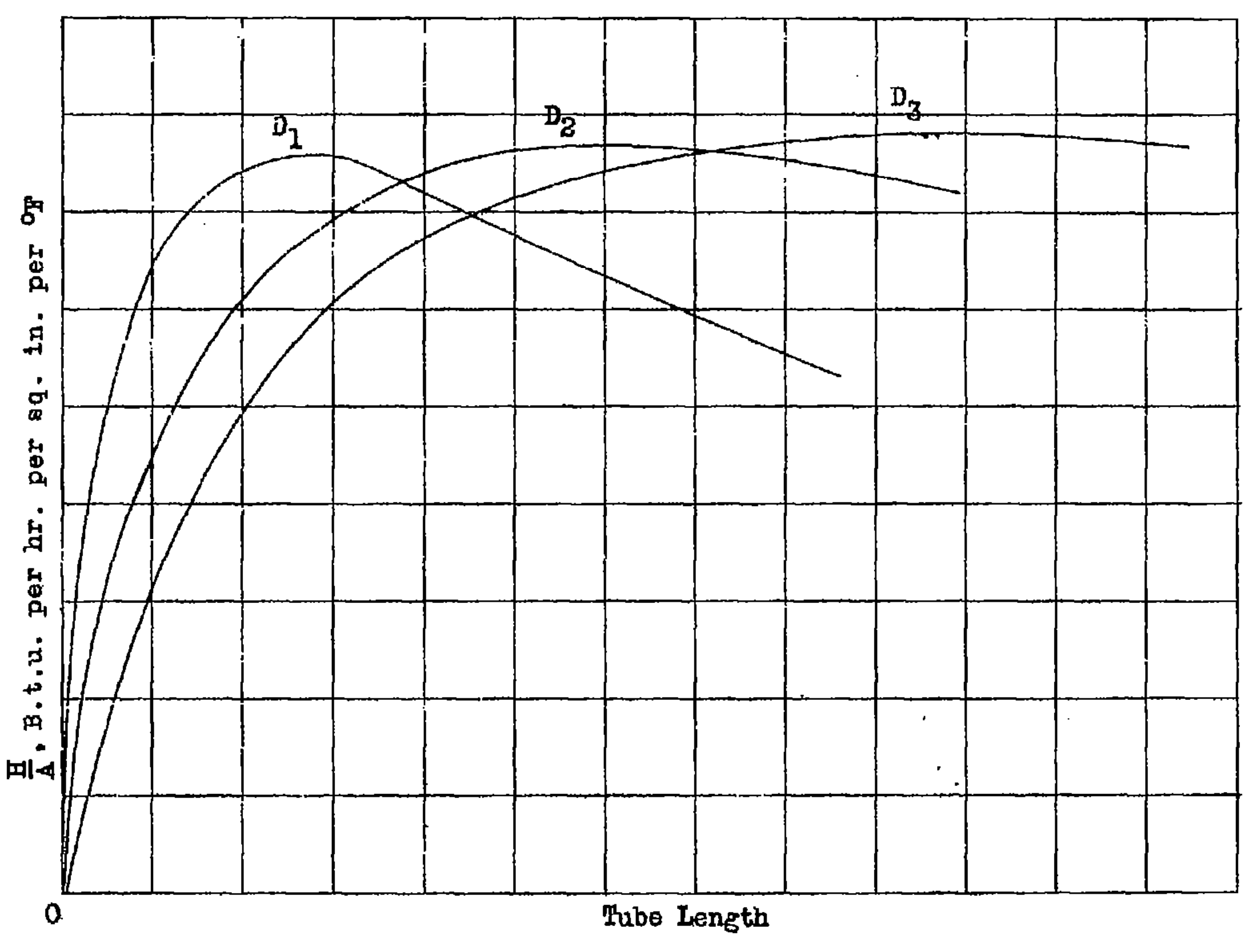

Figure 1.- Variation of heat dissipated per unit frontal area with radiator length for three tube diameters.
D = Diameter, $D_1 < D_2 < D_3$

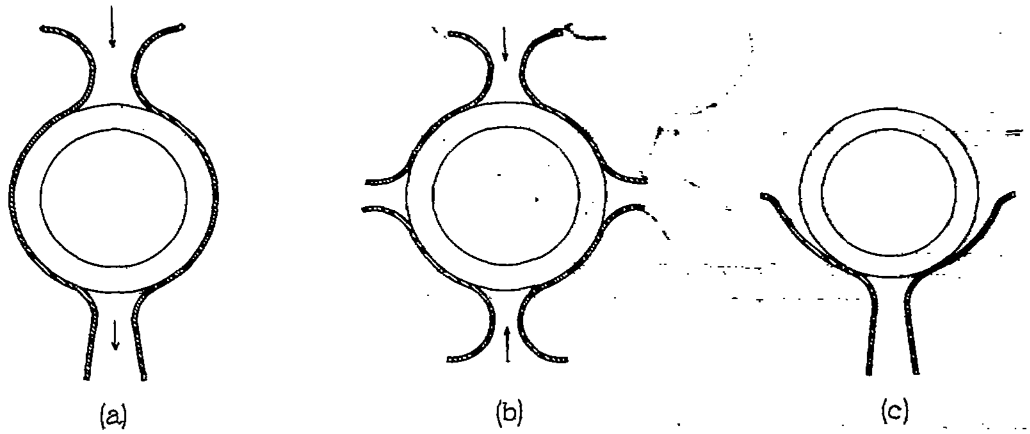

Figure 2.- Illustration of long and short baffles.

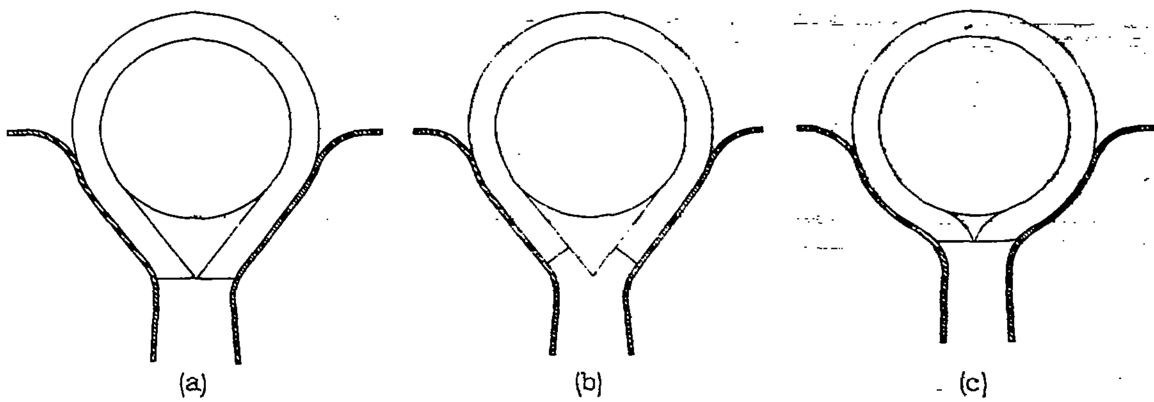

Figure 3.- Three streamlined cylinders.

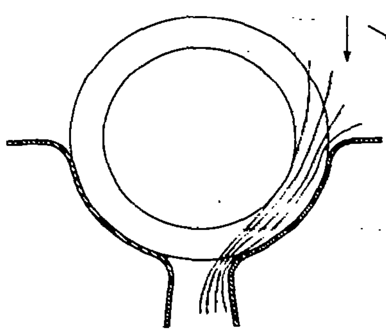

Figure 5.-Air flow through normal baffle.

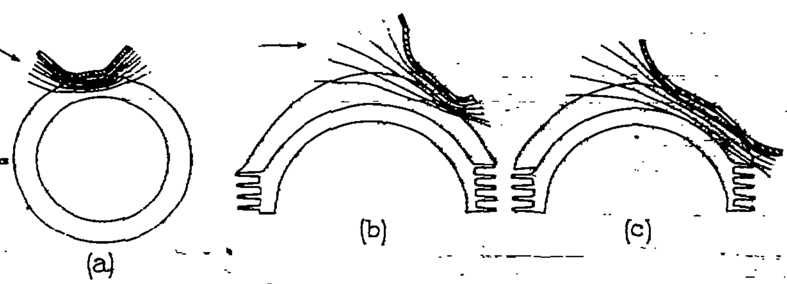

Figure 6.- Air flow with several baffle arrangements.
(a) Short baffle on a circular cylinder.
(b) Poor baffle on the head.
(c) Good baffle on the head.

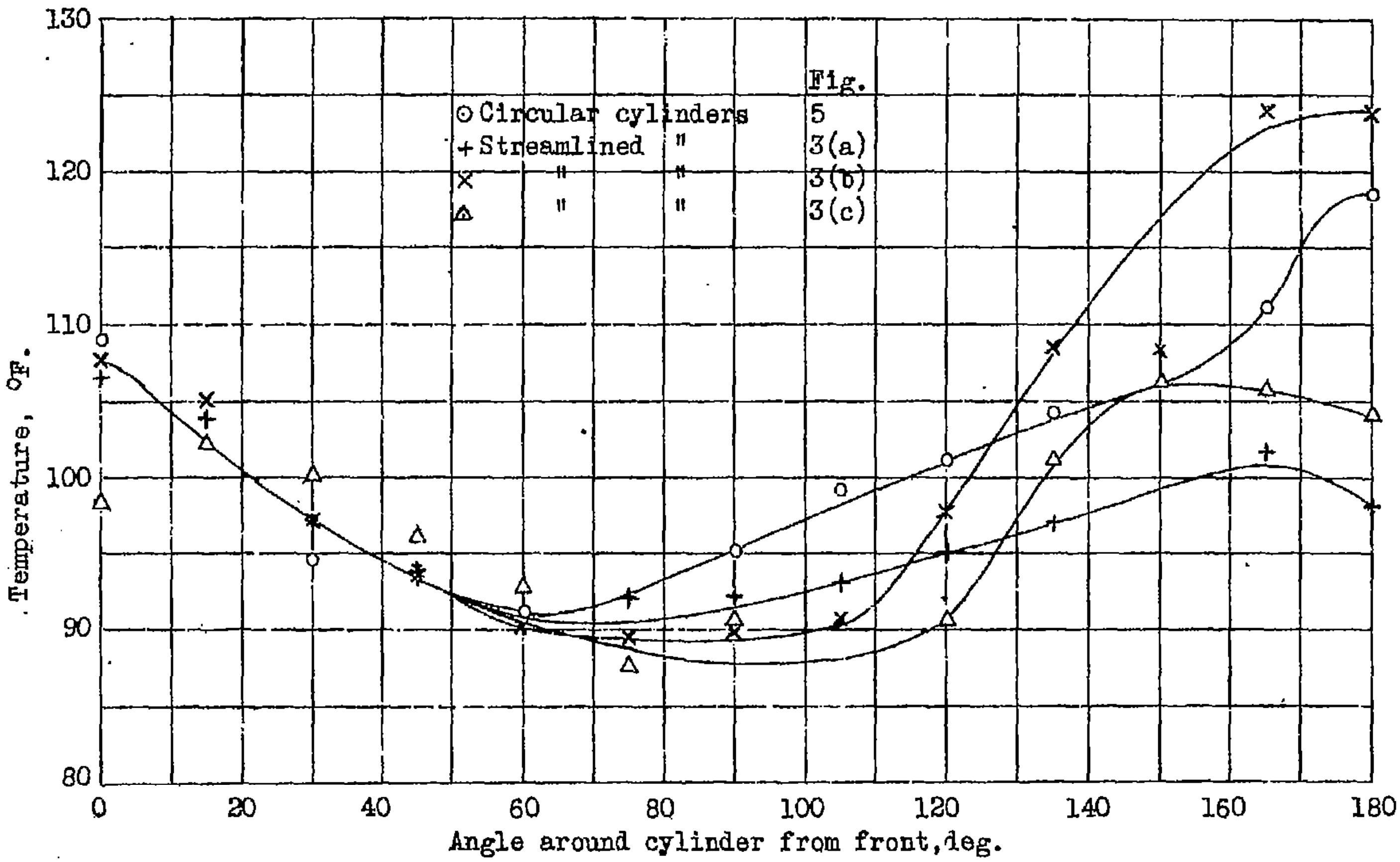

Figure 4.- Temperature distribution for four heated cylinders.